Singularity Overview

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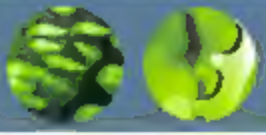
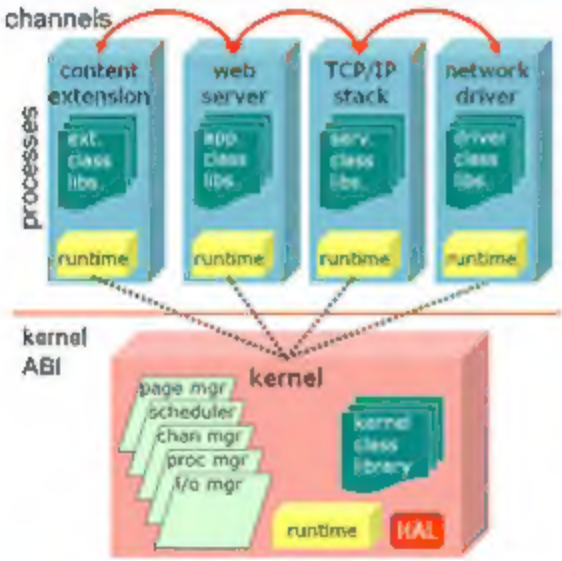
MSR TechFest



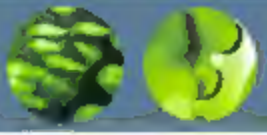
Key Approaches

1. Pervasive use of safe (& analyzable) programming languages
   - type safety and memory safety
   - including device drivers, OS components, applications
2. Improve system resilience despite software errors
   - failure boundaries between components
   - improve extension model
   - explicit error notification
3. Increased verification
   - specification at multiple levels of abstraction
   - closed environments with explicit cross-domain interfaces
   - design for verifiability

Singularity OS

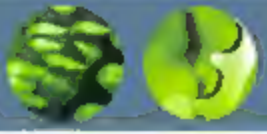


- **Closed Kernel**
  - 95% written in C#
    - 17% of files contain unsafe C#
    - 5% of files contain x86 or C++
  - OS services & drivers in processes
  - kernel closed at boot time
- **Software isolated processes (SIPs)**
  - all user code is verified safe
  - some unsafe code in trusted runtime
  - processes closed at start time
- **Safe and efficient communication via strong interfaces**
  - channels between processes
  - channel behavior is specified & checked
  - checked behavior enables efficient communication
- **Type safety is crux of verification & protection**



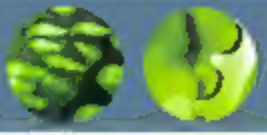
Challenge 1: Pervasive Safe Languages

- Started with C#
  - actually Spec# (= C# + pre/post-conditions and invariants)
  - processes can be written in any safe language (with MSIL compiler)
- Added features to C# for systems programming
  - increase programmer control over allocation, initialization, and memory layout
- Explore language features to support programming and verification
  - message passing communication
  - factoring libraries
  - compile-time reflection



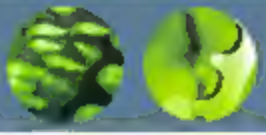
Performance of Safe Languages

- Diverse requirements (not just speed)
  - execution time, memory footprint, pause times, expressibility
    - device drivers should have <100 KB dynamic footprint
    - kernel shouldn't fail due to transient memory exhaustion
    - able to write wide range of applications and devices
- JVM & CLR's design points not always appropriate
  - monolithic runtimes ("one size fits all")
    - powerful, general-purpose environments
    - large memory footprints (~4 MB per process for CLR)
    - long list of dependencies (CLR PAL requires >300 Win32 APIs)
  - JIT compilation
    - introduces complexity, performance overheads
  - runtimes replicate OS features
    - security, threading, configuration, etc.



Small, Customizable, Safe Environment

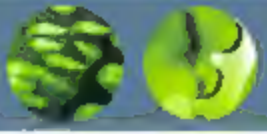
- Singularity modular execution environment
  - runtime, garbage collector, and library selectable on per-process basis
    - reduce runtime overhead
    - enforce design discipline and system policies
  - lightweight, subsetable runtime
  - language support for factoring runtime and libraries
  - compiler support for specializing runtime and libraries
    - remove code for unused/disabled language features
- Ahead-of-time optimizing compilation (MSR Bartok)
- Merge OS & language run time
  - integrate partially redundant features into OS
  - no separate JVM or CLR



Runtime Overhead

	Memory footprint "Hello World" process			
	Singularity	FreeBSD 5.3	Linux 2.6.11 (Red Hat FC4)	Windows XP (SP2)
C - static lib		232K	664K	544K
C++ - static lib		704K	1,216K	572K
C# - w/ GC	408K*			3,750K

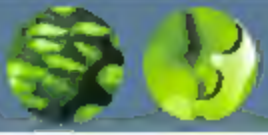
- C# process w/ GC has similar memory footprint to C++
  - minimal process (no GC or exceptions) is ~16K



Challenge 2:

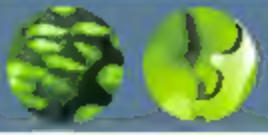
Run-Time Resilience

- Software errors should not cause system failure
- Resilient system architecture
  - isolate system components to prevent data corruption
  - provide clear failure notification
  - implement policy for restarting failed component



Extensibility Through Dynamic Code Loading

- Code loading is common extensibility mechanism
  - DLLs, Java class loading, browser plug-ins, Eclipse, …
- Shared state reduces dependability
  - 85% of Windows crashes are device drivers
    - problem at all levels, not just the OS
  - no isolation boundary between code and extension
- Singularity processes are fundamental unit of failure isolation
  - no dynamic code loading or run-time code generation
    - all code present when process starts execution
  - any extension executes in separate process
    - two closed environments with well-defined interface
  - no shared memory

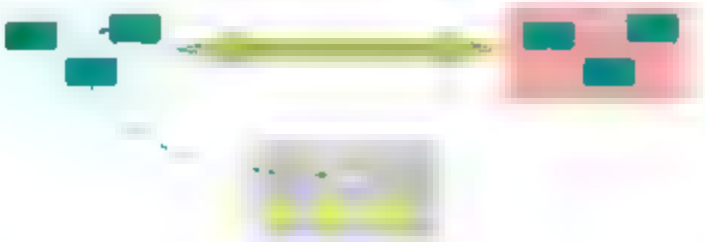


Making Processes Lightweight

- Hardware context switch mechanisms can be expensive
  - use of kernel calls, IPC limited by their cost
- Software isolated processes (SIPs)
  - processes execute only safe or trusted code
  - process is exclusively owner of a set of pages
  - protection and isolation enforced by language safety and kernel ABI design (not hardware)
  - global invariants:
    - no process contains a pointer to another object space
    - no pointers from exchange heap into process
- Closed object space (not address space)

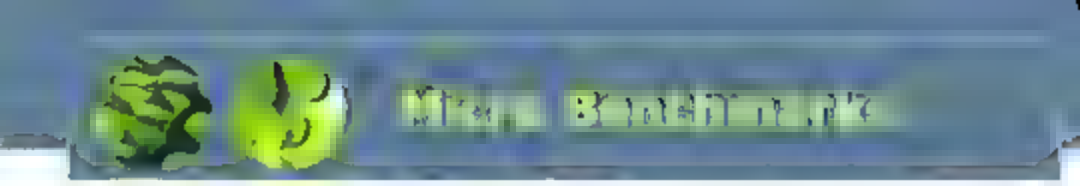
Fast Interprocess Communication

- Channels
  - bi-directional, asynchronous IPC mechanism between two processes
  - contract specifies messages and communication protocol
- "Send & forget" message semantics
  - each message and endpoint owned by at most one process
  - ownership transferred at send
- Correct usage statically enforced
- Efficient implementation



[illegible]

- SIPs are failure containers
  - no shared implementation or state across SIPs
  - process runtimes are distinct
- On SIP failure:
  - clean failure notification on peer channel endpoints
  - resources reclaimed by OS
- Recovery feasible, not automatic or transparent
  - peers can recover and continue



Athlon64 3000+ (1.8GHz) nForce4 SLI	Cost (CPU Cycles)			
	Singularity	FreeBSD 5.3	Linux 2.6.11 (Red Hat FC4)	Windows XP (SP2)
Minimum kernel API call	87	878	437	627
Message request/reply	1,450	13,300	5,800	(LPC) 4,650 (NP) 6,340
Process create & start	300,000	1,030,000	719,000	5,380,000

- Why?
  - all SIPs run in ring 0
  - static verification replaces hardware protection
  - good optimizing compiler (not JIT)

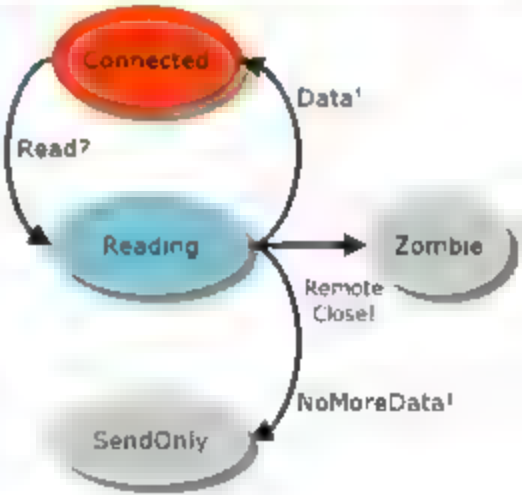
More Verification

- Integrate specifications throughout system
  - language
  - interprocess communication
  - application & device driver descriptions
- Detect errors early, verify code late
  - language safety essential to system integrity

Channel Contract

```
public contract TcpSocketContract {

state Connected : one {
    Read? -> ReadResult
    Write! -> WriteResult

    GetLocalAddress? -> IPAddress
    Connected
    GetLocalPort? -> Port * Connected

    DoneSending? -> ReceiveOnly
    DoneReading! -> SendOnly
    Close -> Closed
    Abort? -> Closed


state Reading : one {
    Data! -> Connected
    NoMoreData! -> SendOnly
    RemoteClose! -> Zombie
}

}
```

? = receive
! = send



Example

Channel Contract

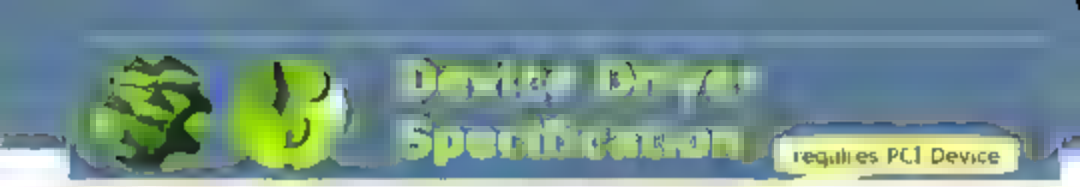
Contract

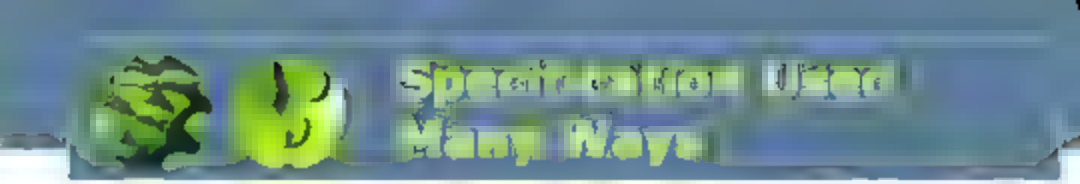
```
public contract TcpConnectionContract {

state Connected : one {
    Read : ReadResult
    Write? : WriteResult

    GetLocalAddress^ -> IpAddress
    Connected
    GetLocalPort^ -> Port * Connected

    DoneSending? -> ReceiveOnly
    DoneReceiving^ : SendOnly
    Close? -> Closed
    Abort? -> Closed
}

state Reading : one {
    Data : Connected
    NoMoreData : SendOnly
    RemoteClose -> Zombie
}

}
```

Client

```
conn.SendRead()
switch receive {
    case conn.Data(readData)
        dataBuffer.AddToTail readData
        return true

    case conn.RemoteClose
        return false
}
```

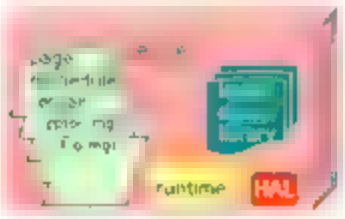
- Application is first-class abstraction with identity
  - code + resources + manifest
- Manifest specifies
  - software components
  - dependencies
  - exported channels
  - hardware or software resource requirements


Device Driver Specification
requires PCI Device
requires 4MB frame buffer (declared in PCI config)
IoMemoryRange frameBuffer,
requires system console buffer
IoMemoryRange textBuffer;
requires VGA I/O ports
IoPortRange control,
requires channel to parent process for control
TRef<ExtensionContract.Exp.Start> pnp.
TRef<ServiceProviderContract.Exp:Start> video;
exports channel for clients to access video device



Specification Used Many Ways

Driver (Source+



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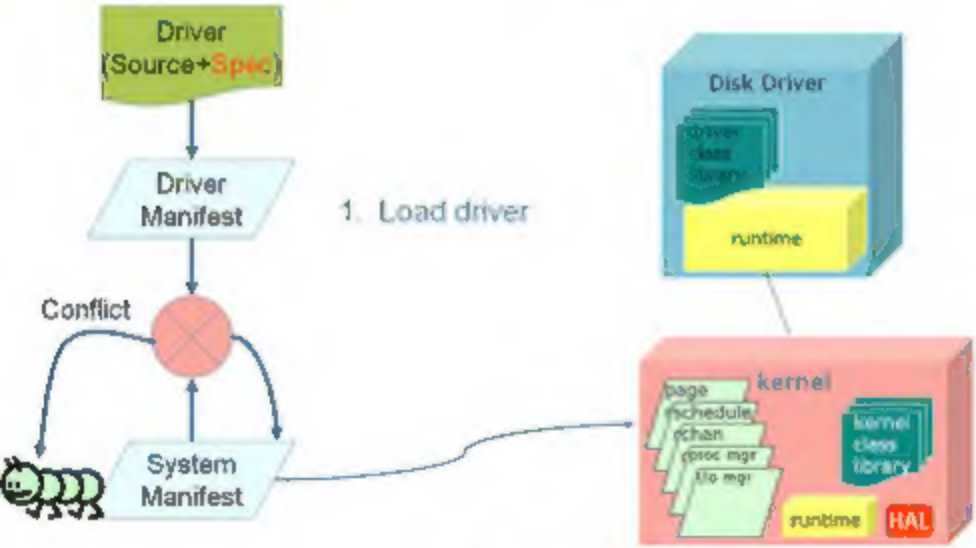

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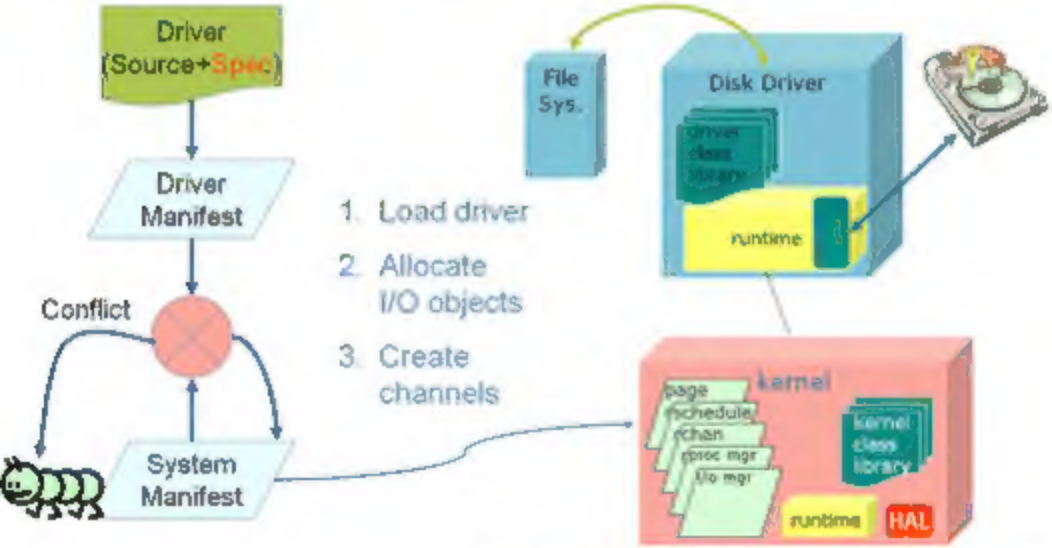

Driver Verification

- Verification ensures
  - never install an program that will break another program
  - never start a program without appropriate resources
  - never grant a program access to undeclared resources
- All of these checks performed statically

Summary

- Singularity is basis for more dependable systems
  - pervasive use of safe programming languages
  - lightweight, closed, customizable run-time environment
  - verifiable specification of system behavior
- Working research prototype
  - driving research in large number of areas
- More information:
  - http://research.microsoft.com/os/singularity
    MSR Tech Report MSR-TR-2005-135